Measurement Science in the Extreme Ultraviolet

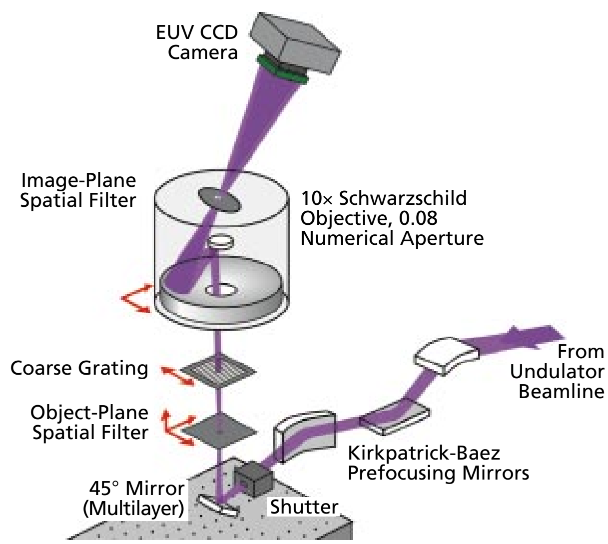
Testing Advanced Optics for Printing Integrated Circuits

Metrology, the science of measurement, plays a key role in new technologies. In order to make something accurately, you have to be able to measure it at least as accurately. Metrology is thus a key issue for the integrated-circuit (IC) industry, which uses ultraviolet light to etch the finely detailed patterns in computer chips in a process called projection lithography. The industry would like to produce chip patterns with smaller features, packing up to ten times more circuits in the same area by 2004, but feature sizes now in mass production are limited by the wavelength of ultraviolet light. This problem could be solved by using extreme ultraviolet (EUV), which has much shorter wavelengths, but there's a catch. Conventional lenses used for UV light are opaque to EUV light. To overcome this difficulty, researchers are developing new imaging optics for EUV light, using curved mirrors coated to increase their reflectivity. These mirrors must be so accurately shaped and have surfaces so smooth that advanced measurement techniques are needed to judge their quality.

EUV Interferometry

Researchers at the ALS are addressing this challenge with a new measurement tool that operates at EUV wavelengths. There are three reasons for them to take this "at-wavelength" approach (evaluating an optic using the same wavelength of light with which the optic will be used) rather than using existing visible-light measurement systems. First, the optical flaws they must detect are only 1/2500 the size of a visible light wave. Measurements so fine are beyond present technology. Although visible-light techniques may improve, with EUV light the same flaws are 1/50 of a wavelength in size. Second, visible light reflects off only the outer surface of the mirror coating, which consists of multiple layers only a few atoms thick, and is insensitive to the layered coating structure that is critical for EUV reflection. Third, at-wavelength measurements demonstrate actual mirror performance.

The new instrument, called a phase-shifting, point-diffraction interferometer (PS/PDI), starts with a very bright, narrow beam of EUV light from the ALS, focused through a very small pinhole to produce a uniform spherical wavefront. (Even though pinholes exclude most of the incoming light, the brightness of the beam ensures that enough light passes through to allow rapid data acquisition.) A diffraction grating splits the light into several partially overlapping beams, two of which reflect from the mirrors in the test optic. One beam serves as the test beam and passes through a square window large enough (5 μm on a side) to allow the wave to pass through without distortion, thereby preserving the aberrations it picks up from any flaws in the test optic. A neighboring beam passes through another tiny pinhole, again becoming a uniform spherical reference wavefront. Where the aberrated test wave and the reference wave overlap, they interfere and produce a pattern



This diagram of the main elements of the phase-shifting, point-diffraction interferometer (PS/PDI) shows how extreme ultraviolet (EUV) light from the ALS is used to analyze a Schwarzschild objective (lens) comprising two spherical mirrors. The EUV light from the ALS is split into two beams that overlap and interfere at the location of an electronic (CCD) camera. The pattern of light and dark fringes recorded by the camera provides the raw data for the analysis.

of light and dark fringes that is recorded on an electronic (CCD) camera. Mathematical analysis of this fringe pattern, including the removal of systematic experimental errors, yields information about flaws in the test optic.

First Test Results

In a prototype EUV projection lithography system now being tested, a Schwarzschild objective (a pair of nested spherical mirrors) produces a demagnified image of the pattern in a mask, transferring it to a computer chip that is 10 times smaller than the mask pattern. Recent experiments to evaluate such a 10× Schwarzschild objective have enabled researchers to characterize the PS/PDI's precision. Repeating the same measurements in many ways, each time completely realigning the instrument, the researchers have established an excellent repeatability in the measured aberrations, which were the same to within ± 1/125 wavelength (rms). The tougher job of verifying high accuracy by identifying systematic measurement errors is still under way. Some systematic errors can already be subtracted, and a so-called null-test procedure should reduce several more. Moreover, projection lithography experiments with the Schwarzschild objective produced results consistent with predictions based on PS/PDI measurements, suggesting that the remaining errors are small.

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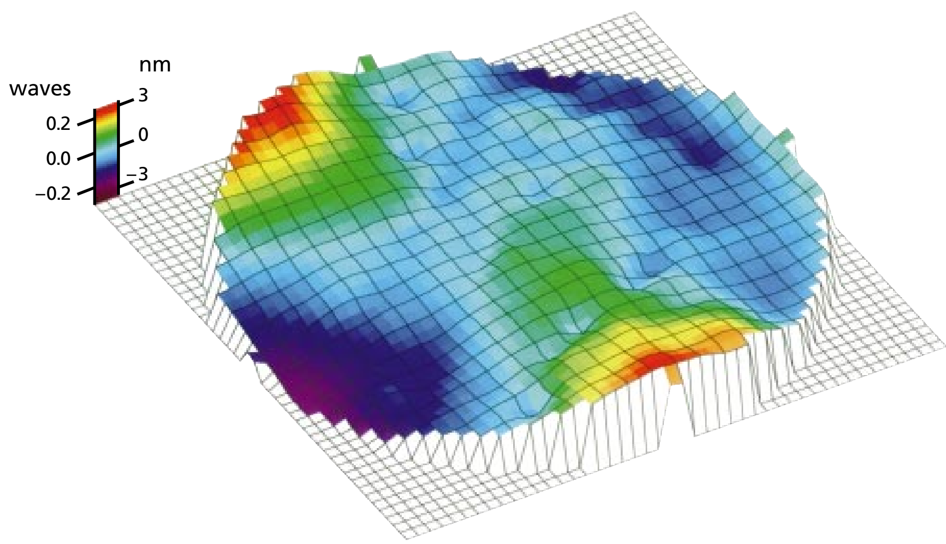

From the fringe patterns formed at the intersection of the test and reference waves from the phase-shifting, point-diffraction interferometer, researchers can calculate a wavefront-aberration phase map, above, that yields information about flaws in the test optic. The height (measured in wavelengths of the extreme ultraviolet light, about 13.4 nm in these experiments) is a measure of the optic's deviation from perfect shape.